CONSTRUCTION MATERIALS

DOI 10.15826/rjcst.2016.1.010 УДК 691.966

Kim K.-D.[1], *Akmalayev K.*[2], *Zhakipbekov Sh.*[3], *Sartayev D.*[4]

[1]Seoul National University of Science and Technology (SeoulTech), Seoul, Republic of Korea

[2–4]The Kazakh national research technical university named after K. I. Satpayev, Almaty, Republic of Kazakhstan

E-mail: [1] *kikw@chol.com,* [2] *7598154@mail.ru*

A STUDY ON THE MECHANISM OF EARLY-AGE CONCRETE UNDER CURING CONDITIONS

Abstract. It is known that the control method of hydration heat and curing temperature, which arise during the construction process of cement concrete structure, exercises great influence on compressive strength, durability, water-tightness and long-term performance of the concrete. Provided that high heat of hydration acts as a factor generating thermal crack and causes structural problem at concrete structure, we cannot secure protective performance of the structural steel inside the concrete but also will have harmful damage in respect of social trust as well as economic loss caused by continuous repairing and reinforcing works which are necessary for remedying the fault. Therefore, we studied and measured heat of hydration, curing temperature and compressive strength at the early-age curing of cylinder specimen and mock-up structure in order to find out the method of concrete construction management with outstanding construct ability and upgraded economic feasibility. In this study we dealt with the concrete mechanism and the maturity method with which we can control and/or detect the probability of crack generation in advance.

Keywords: heat of hydration, curing temperature, compressive strength, mass concrete, maturity, early age concrete, thermal crack.

Ким К.-Д.[1], *Акмалаев К.*[2], *Жакипбеков Ш.*[3], *Сартаев Д.*[4]

[1] Сеульский национальный университет науки и технологии, Сеул, Республика Корея

[2–4]Казахский национальный исследовательский технический университет им. К. И. Сатпаева, Алматы, Республика Казахстан

E-mail: [1] *kikw@chol.com,* [2] *7598154@mail.ru*

МЕХАНИЗМ ТВЕРДЕНИЯ БЕТОНА В РАННЕМ ВОЗРАСТЕ

Аннотация. Известно, что метод управления теплотой гидратации и температуры твердения бетона, которые возникают в ходе бетонирования, оказывает большое влияние на прочность при сжатии, долговечность, герметичность и долгосрочную работу бетона. Учитывая, что тепловые гидратации являются фактором, вызывающим тепловые трещины и структурные проблемы в бетоне, невозможно обеспечить защиту металлической арматуры в бетоне, а также это влечет за собой потерю социального доверия и экономический ущерб, вызванный постоянным ремонтом и усилением. Поэтому мы занимаемся изучением и измерением теплоты гидратации, температуры твердения и прочности на сжатие на ранней стадии твердения цилиндрических образцов и моделей конструкций, для того чтобы найти реализуемый в строительстве и экономически обоснованный метод возведения бетонных конструкций. В данной статье описывается механизм бетонирования и метод контроля за нарастанием прочности, с помощью которого можно контролировать и/или определять вероятность образования трещин.

Ключевые слова: тепловая гидратация, температура твердения, прочность на сжатие, монолитный бетон, зрелость бетона, бетон на раннем возрасте, термическая трещина.

1. Introduction

It is known that the control method on heat of hydration and curing temperature arising during the construction of a concrete structure have a great influence on compressive strength, durability, water-tightness and long-term performance of concrete. Accordingly, we intended to grasp thermal and strength characteristics which are the main mechanism of concrete. To this

Fig. 1. Curing of specimens

end, we made concrete specimens and conducted tests under two different curing conditions to study the way how structure size and curing condition influence the concrete. Through this study, we intend to digitize and quantify temperature control method into values and thus make a contribution to the construction of outstanding concrete structures by utilizing the values.

2. Test plan & method

2.1. Test plan

In order to grasp hydration heat of early-age concrete in curing and the property change of concrete which is varied according to the change of hydration heat and curing temperature, we made cylinder specimen (Ø 150 mm x H 300 mm) and mock-up structure (W2, 400 mm x B1, 200 mm x H1, 700 mm) using concrete with design based compressive strength $f(28)$ = 30 MPa, and measured the development of temperature and strength of the concrete on a real-time basis [1–3].

2.2. Test method

2.2.1. Specimen product & Curing

We made the specimens and carried out tests according to KSF 2403. As for the test of the cylinder specimen, we carried out, side by side; water curing with standard curing (reference temperature of 20±2 °C) and atmosphere curing with temperature change. For the test, we installed temperature sensors (t-type thermocouple) inside of the specimens and the mock-up structure to measure temperature (Fig. 1).

2.2.2. Type of test

We performed the 1st test at the very early age of 6 hours in order to figure out thermal and strength characteristics from the cylinder specimen in curing after concrete casting (Table 1). To this end, we carried out the next tests on the specimens of curing under standard and atmosphere curing conditions at age 8, 12, 18, 24, 48, 72, 168, 334 and 672 hours after concrete casting. We run tests ten times.

Fig. 2. Specimen’s measurement and test

Table 1

Destructive testing & non-destructive testing

Item	Measuring type	Measuring instrument	Remarks
Destructive testing	Compressive strength (P)	Max. 1000 kN	KSF 2405
Non-destructive testing	Ultrasonic speed (Vp)	Pundit (54KHz)	Cycle time for frequency (µs)
	Rebound hardness (R)	Digital test hammer	10 N/mm^2~60N/mm^2
	Heat of hydration	ConReg system 706	t = 20 °C, Equivalent age

3. Analysis of the test results

3.1. Results of compressive strength testing

Initial-stage compressive strength values of age 6 hours were indicated as 2.84 MPa at standard curing and 2.73 MPa at atmosphere curing. However, after age 24 hours, the strength values of the specimen of standard curing were greater than those of the specimen of atmosphere curing, it was judged that the reason was facilitatiotn of development of hydrate by continuous water supply, resulting in strength increase [4—6].

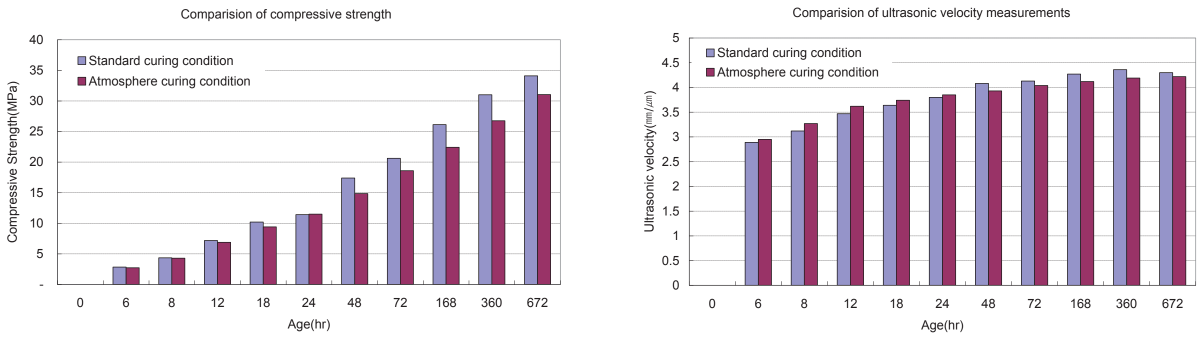


Fig. 3. Results of compressive strength & ultrasonic velocity measurements

3.2. Results of ultrasonic velocity measuring

We were able to measure the strength values of the specimens of age 6 hours by ultrasonic velocity instrument. In this measurement, the values of standard curing were less than the values of atmosphere curing until age 24 hours, which means curing speed in atmosphere is faster. However, after age 24 hours, ultrasonic velocity of specimen in standard curing was gradually increased and became faster than the speed of the specimen in atmosphere [7—9]. In this regard, we found out that the result of the test of ultrasonic velocity is similar to that of the compressive strength test (Fig. 3).

3.3. Results of rebound hardness measuring

As the result of analyzing of strength values obtained through the measurement of rebound hardness by ages, we noticed that during age of 1—3 days we could not get calculated values due to the shortage of surface strength. Accordingly, we could not rely on the first three days values. Meanwhile, rebound hardness of the specimen at atmosphere curing became greater than those of the specimen at standard curing after age 7 days.

In addition, we checked the compressive strength of mock-up specimen at age 28 days through rebound hardness test and found out the strength was

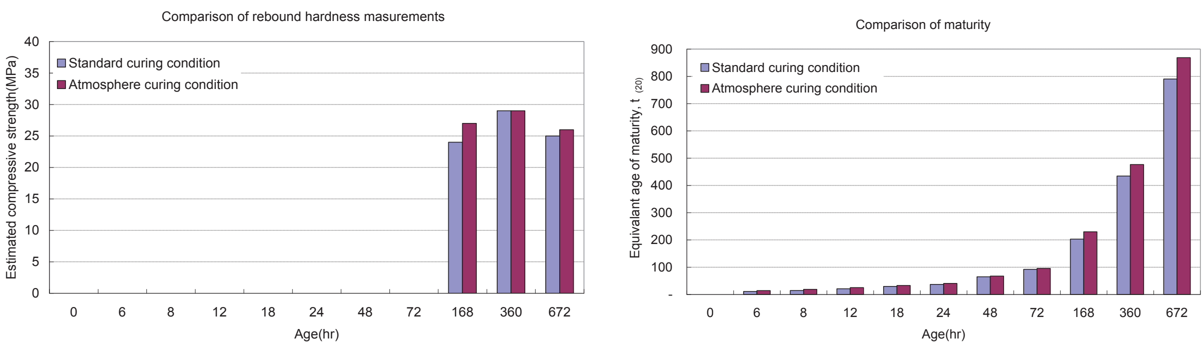
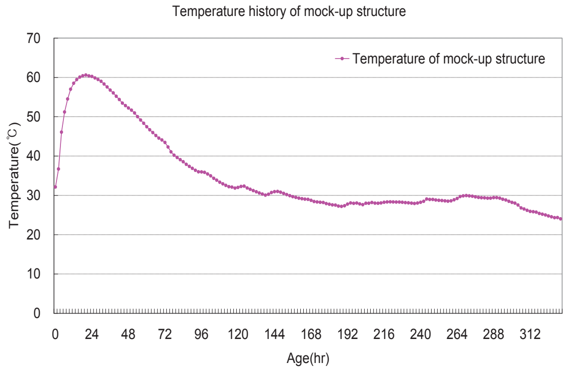


Fig. 4. Result of rebound hardness & maturity measurements



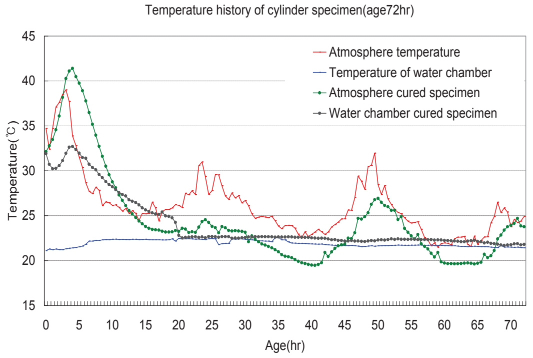


Fig. 5. Temperature history of mock-up structure & cylinder specimen

35 MPa, which were pretty similar to the compressive strength value of the cylinder specimen at standard curing [10–12]. We concluded that the reason was that covering the top surface of the concrete with P. E. film for 7 days after concrete casting kept moisture from evaporating and thus contributed a lot to strength development of the mock-up specimen (Fig. 4).

3.4. Theory of maturity and equivalent age

History of development of hydration heat and computation of equivalent age are shown in Fig. 5. Maturity index on equivalent age of age 28 days should be 672 as the equivalent time transformed on the basis of curing temperature of t = 20 °C and at this moment, the index of compressive strength should have been the same as the one of target standard strength [13, 14]. However, as the result of the test of cylinder specimen, we detected the following facts.

Under standard curing condition

Equivalent age: t (20) = 868 hours, Compressive strength: f (28) = 34 MPa

Under atmosphere curing condition

Equivalent age: t (20) = 790 hours, Compressive strength: f (28) = 31 MPa

Judging from the above facts, we conclude that concrete maturity is greatly influenced by hydration heat and curing temperature at early-age curing (Fig. 6).

3.5. History of development of hydration heat at mock-up structure

Average maximum temperature developed at mock-up specimen was indicated as 60.6 at age 20 hours. In case of mass concrete, we noticed that computation of equivalent age was made prior to maximum equivalent conversion time of 672 hours due to the nature of heat, which means that mass concrete at early age is influenced by high hydration heat.

4. Conclusions

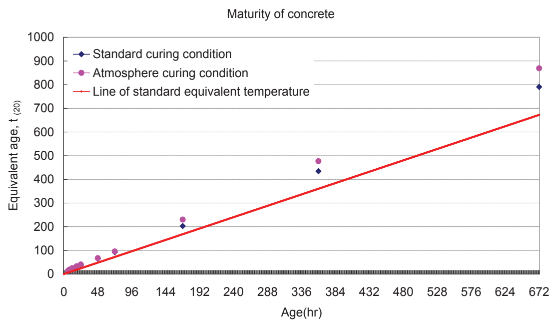
Through this study, we found out the following facts on mechanism of early-age concrete under two different curing conditions.

1. Heat of hydration and curing temperature, both of which arise from mass concrete, play a great role in development of early strength.

2. Rapid temperature rise inside mass concrete makes compressive strength increase, but produces internal thermal stress causing thermal crack on the concrete.

3. In the mass concrete, approximate 70 % of target strength is developed within about 100 hours on the basis of equivalent age t (20) owing to the internal hydration heat.

4. As high hydration heat at early age makes compressive strength of long-term age decline, appropriate control method of curing temperature makes it possible to control temperature crack.



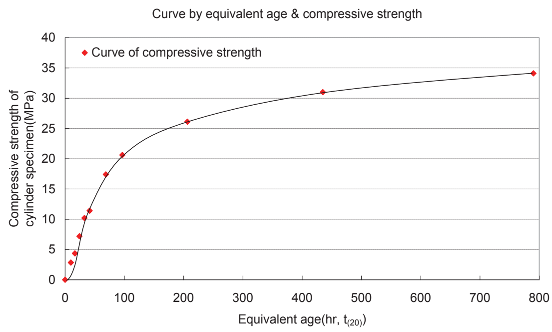


Fig. 6. Comparison of concrete maturity and estimation curve of compressive strength by ages

5. Maturity method, through which we can estimate compressive strength by converting functional relation between temperature and strength of concrete into equivalent age, can be applied to concrete curing. In the future, the development of a new program, which can compile required average strength by mix into database, is required so that we can apply the maturity theory to concrete curing with ease.

References

1. Neville A. M. *Property of Concrete*. New York, John Wiley & Sons, 1996, pp. 269–284.
2. *ASTM C 1074–98. Standard Practice for Estimating Concrete Strength by the Maturity Method*. 1999, vol. 04.02, pp. 540–547.
3. Lee I. K., Kim K. D., Kim J. S., Kim T. Y. Heat of Hydration and Thermal Crack Control for Floating Concrete Mass Foundation. *Journal of the Korea Institute for Structural Maintenance and Inspection*, KSMI, 2010, vol. 14, no. 1, pp. 156–164.
4. Kim K. D. *A Study on the Early-Age Strength Increasing by Monitoring of Concrete Temperature Hysteresis. Ph. D. dissertation*. Joongbu University, Department of Civil Engineering, 2009.
5. Kim K. D., Kim C. H., Choi H. S., Jeon C. K. Evaluation of Strength and Temperature Hysteresis of the Steam Cured Concrete. *Journal of the Korea Institute for Structural Maintenance and Inspection*, 2009, vol. 1, pp. 277–278.
6. Kim K. D., Kim C. H. Study for the Strength Mechanism and Thermal Control of the Curing Concrete by Early Age. *Magazine of Korea Concrete Institute*, 2007, vol. 19, no. 2, pp. 1049–1052.
7. Kim K. D., Kim C. H., Kim J. C., Oh S. Y. An Experimental Study on the Effect of the Atmosphere Curing Condition on Mass Concrete. *Magazine of Korea Concrete Institute*, vol. 19, no. 1, pp. 791–794.
8. Kim K. D., Kim C. H., Lee C. Y., Hwang M. K. An Experimental Study on the Effect of the Early Age Curing Condition on Mass Concrete. *Magazine of Korea Concrete Institute*, 2006, vol. 18, no. 2, pp. 685–688.
9. Jeong D. K., Lee H. S. The Effect of Curing Temperature for Strength Development in RPC. *Magazine of Korea Concrete Institute*, 2010, vol. 22, no. 2, pp. 177–178.
10. Ko H. B. The Effect of Curing Temperature History on Concrete Strength Development. *Magazine of Korea Concrete Institute*, 1998, vol. 10, no. 5, pp. 89–100.
11. Jang H. S. *Study on ultrasonic velocity and rebound hardness method for structural properties of concrete with mixed fly ash according to the replacement ratio of recycled coarse aggregate*. Master's thesis. Hanyang University, Department of Civil Engineering, 2011.
12. Kim J. K., Moon Y. H., Eo S. H., Choi E. K. The Effect of Different Curing Time and Temperature on Compressive Strength of Concrete. *Magazine of Korea Concrete Institute*, 1998, vol. 10, no. 3, pp. 143–152.
13. Yang S. C., Choi K. I. Application of Concrete Maturity on Construction Fields. *Magazine of Korea Concrete Institute*, 1997, vol. 9, no. 4, pp. 42–48.
14. Oh B. H., Lee M. K., Hong K. O., Kim K. S. Development of Predication Model of Early-Age Concrete Strength by Maturity Concept. *Magazine of Korea Concrete Institute*, 1996, vol. 8, no. 3, pp. 197–207.